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ADVANCED ELECTROMAGNETIC METHODS FOR AEROSPACE VEHICLES

Annual Performance Report
(July 1, 1994 - June 30, 1995)

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I. Introduction

The four main topics addressed by the Advanced Electromagnetic Methods for Aerospace Vehicles during this research period are:

a. Antenna Pattern Prediction Methods, Modelings and Computer Codes

b. HF Antennas

c. High Intensity Radiated Field (HIRF) Penetration

d. Antenna Technology

Each of the above topics is briefly addressed, reporting on the progress made and outlining future work to be accomplished.

II. Antenna Pattern Prediction Methods, Modelings, and Computer Codes

An updated version of the Numerical Electromagnetics Code (NEC), the NEC-4, was recently obtained by the Advanced Helicopter Electromagnetics (AHE) Program at Arizona State University. The updated version of NEC includes among other a graphics interface for viewing the NEC model, capabilities to plot and interpolate impedance-versus-frequency curves, and plot radiation patterns. The performance of a parallel Finite-Difference Time-Domain (FDTD) code implemented on a MasPar computer and used for antenna input impedance calculations was compared with a similar code on an IBM RS6000 workstation. Speedups of up to 57 times were obtained. Recently, a new geometry visualization code, the GEOMVIEW, has been downloaded from the internet and it is currently being used to view Finite Element Radiation Model (FERM) generated geometries of helicopter structures. This package can replace DISSPLA, which runs only on a VAX workstation and requires licensing fees. Also, the issue of electrical connectivity of a strip antenna model on a conducting ground plane was revisited and improved computed results for input impedance and radiation patterns were obtained.

III. HF Antennas

In a continuing effort to validate available electromagnetic codes for High Frequency (HF) antenna modeling on helicopters, the FDTD method was applied to compute the input impedance of the 24′ loop on the Apache in the frequency band of 3-30 MHz. The computed results were compared with available full-scale and 10:1 scaled measurements. In addition, coupling effects and proper modeling using the NEC code was investigated. In an effort to validate coupling predictions, both 10:1 scaled measurements and NEC predictions of coupling between the 14′ loop and 24′ loop or inverted-L antennas on the Apache were performed. There are, however, large differences between the computed and measured coupling values. NEC guidelines for accurate modeling of coupling were investigated and developed. These guidelines were derived based on the fact that the S_{12} and S_{21} computed coupling parameters should be equal for a reciprocal network. It is found because of geometrical discretization of the airframe, the numerical data from the NEC did not satisfy $S_{12} = S_{21}$. Factors contributing to the discrepancy and ways to reduce the difference in the two computed parameters are presented. Also, HF loop impedance modulation measurements were conducted. In these measurements the effect of the rotor position on the antenna input impedance was measured at resonance.

IV. High Intensity Radiated Field (HIRF) Penetration

A preliminary study on HIRF penetration was conducted. For this analysis an available FDTD code for scattering has been used and applied on a partially conducting/partially composite NASA scale helicopter model. Penetration through the helicopter's cockpit window was examined at the single frequency of 500 MHz (7:1 scale). The effect of using graphite material for the cockpit windows and the an incoming plane wave at different incidence angles on the level of the penetrating fields was examined.

This study generated interest among the AHE members and several extensions for further investigation were suggested. First, HIRF testing is required over a very wide frequency range (up to 8 GHz) producing a very large electromagnetic problem in terms of available computational resources. To make the most out of the numerical method, a highly vectorizable and modularized FDTD code is required. This code eventually will be ported into a parallel computer for even better utilization of available computational resources. The second issue was the ability to perform internal geometrical modeling of the helicopter. The current version of the GEOMfdtd code that processes the geometry can only perform surface discretization. Interior details would have to be added externally or manually. These issues are currently being investigated and progress will be reported in future performance reports.

V. Antenna Technology

Experiments to design circularly polarized ferrite-loaded cavity-backed slot antennas were performed. Two different feed configurations were designed and tested, however, both experiments did not indicate successful operation of circular polarization. Some additional feed configurations will be considered in the future. In an effort to examine the discrepancies between the measured and computed ferrite-loaded cavity-backed slot antenna parameters (input impedance, gain), the effects of having a nonuniform magnetic bias field in the cavity were examined using a two-dimensional hybrid finite element/moment method code. A nonuniform magnetic field bias affects the predictions when the bias field is lower than the saturation level.

ABSTRACTS OF JOURNAL AND CONFERENCE PUBLICATIONS

1. C. A. Balanis, W. Sun, P. A. Tirkas, G. C. Barber, "Advanced Helicopter Electromagnetics: Industry, Government and University,"**1994 IEEE MILCOM Conf.** (Fort Monmouth, NJ), pp. 1-6, Oct. 2, 1994.

   The Advanced Helicopter Electromagnetics (AHE) was initiated at Arizona State University on January 1, 1990, to address research needs on developing analytical and measurement methods for helicopter EM applications. The AHE program is a coalition of research and education efforts supported by aerospace industry, federal government agencies and state government. Under the support of the AHE members and the joint effort of the research team, significant progress has been achieved. The research effort has focused on practical helicopter electromagnetic problems, such as antenna pattern modeling and prediction, composite materials, HF antennas, conformal antennas for UHF and possibly VHF, and scale model measurements. This paper provides a brief review of the AHE program through representative examples of some of the problems that were investigated.

2. W. Andrew, C.A. Balanis, C. Birtcher and P.A. Tirkas, "Finite-Difference Time-Domain of HF Antennas,"**1994 IEEE MILCOM Conf.** (Fort Monmouth, NJ), pp. 7-11, Oct. 2, 1994.

   In this investigation, the FDTD method with higher-order absorbing boundary conditions is used to model and predict the input impedance and the far-field radiation of electrically short antennas. Far-field radiation results are presented and compared with measurement for HF loop (towel bar) and inverted-L antenna elements used at 10 MHz mounted on a helicopter-like body. Wideband input impedance predictions and measurements are also presented. The computed radiation patterns and input impedance compare well with measurements.

3. P. A. Tirkas, J. Peng, C. A. Balanis, G. C. Barber, "Electromagnetic Interference and Interaction With Complex Helicopter Structures,"**1994 IEEE MILCOM Conf.** (Fort Monmouth, NJ), pp. 12-16, Oct. 2, 1994.

   Electromagnetic intrerference and interection with complex helicopter structures is examined using general purpose electromagnetic codes such as the Numerical Electromagnetics Code (NEC), Electromagnetic Surface Patch (ESP) code and a Finite-Difference Time-Domain (FDTD) code. The geometry of a generic NASA helicopter model (7:1 scale) is processed using the GEOM which is a general geometry preprocessing code that was developed at Arizona State University. Initially, the interference effect of using two wire antennas on the helicopter is analyzed by examining their effect on the far-field radiation pattern, using the NEC and ESP. Then the FDTD is applied for the simulation of plane wave penetration into the helicopter fuselage which was assumed partially conducting/partially composite.

4. C.A. Balanis, P.A. Tirkas, W.V. Andrew, C.R. Birtcher, and G.C. Barber, "Finite-Difference Time-Domain Method for Helicopter Antennas and EM Field Penetration," **Appl. Comput. Electromag. Soc. Newsletter**, Vol. 10, No. 1, pp. 21-26, Mar. 1995.

   In this paper the application of the finite-difference time-domain (FDTD) method to helicopter antennas, antenna coupling and electromagnetic penetration are presented. The computed input impedance and far-field gain of a HF towel-bar antenna mounted on the surface of the Apache helicopter are compared with available measurements. Also, penetration into a partially conducting/partially composite helicopter airframe is examined. A preprocessing geometry program used in generating the FDTD geometry by using solid surface helicopter geometries is also presented.

5. W.V. Andrew, C.A. Balanis and P.A. Tirkas, "A Comparison of the Berenger Perfectly Matched Layer and the Lindman Higher Order ABCs for the FDTD Method," **IEEE Microwave Guided Let.**, Vol. 5, No. 6, June 1995 (in press).

   Higher-order absorbing boundary conditions are compared to the recently introduced Berenger perfectly matched layer (PML) absorbing boundary conditions (ABC). Reflections caused by the ABCs are examined in both the time and frequency domains for the case of a line source radiating in a finite computational domain. It is shown that the PML ABC significantly reduces reflections from the truncation of the computational grid when compared to the 7^{th} order lindman ABCs. Also, except for at low frequencies, higher-order absorbing boundary conditions are no better than 2^{nd} order Mur absorbing boundaries.

6. P.A. Tirkas, C.A. Balanis, W.V. Andrew, and G.C. Barber, "High Intensity Radiated Field (HIRF) Penetration in Helicopters," **1995 IEEE AP-S Internat. Symp.**, (Newport Beach, CA), June 1995 (to be presented).

   Modern military and civilian aircraft use digital systems to control life-critical functions such as the engines, sensors, fuel systems and actuators. These digital flight control systems are vulnerable to external phenomena such as cosmic radiation, lightning, or high-intensity radiated fields (HIRF). Modern integrated circuits with higher densities and speed are more sensitive to HIRF. Also, composite materials, despite their advantages in strength, weight and cost, provide less shielding than aluminum. Because of these factors, the need to avoid digital upsets of electronic systems exposed to HIRF has become of great interest to industry and government agencies.

   The level of field penetration is dependent, among other factors, on the structure of the aircraft, the size and material at the windshield, the thickness, shape and type of material of the aircraft fuselage and the type of communication systems installed on the aircraft. The field penetration level also depends on the type of electromagnetic threat striking the aircraft. Possible factors that can have significant influence include, among others, the frequency or bandwidth, the maximum intensity, and the direction of the incoming electromagnetic threat.

7. W.V. Andrew, and C.A. Balanis, "FDTD Analysis of Apache Helicopter HF Antennas," **1995 IEEE AP-S Internat. Symp.**, (Newport Beach, CA), June 1995 (to be presented).

   The FDTD method with the recently introduced Berenger Perfectly Matched Layer (PML) absorbing boundary conditions (ABCs) is used to analyze radiation characteristics of an HF antenna on the metallic airframe of the AH-64 Apache helicopter. The antenna of interest is an experimental 14′ "towel-bar" used in the 2-30 MHz band. A companion 24′ HF antenna is mounted on the opposite side of the helicopter tail boom. The FDTD predictions compare well with experimental results from an operational Apache helicopter and with measured data obtained using an approximate 10:1 scale model of the Apache.

8. J. Peng and C.A. Balanis "Coupling Prediction of HF Antennas Mounted on Helicopter Structures Using the NEC Code,"**1995 IEEE AP-S Internat. Symp.**, (Newport Beach, CA), June 1995 (to be presented).

   In this paper the NEC code is applied to coupling problems involving complex helicopter structures at HF frequencies. At HF frequencies, the electrical sizes become very smal, and the NEC code is used near its lower limit which requires careful geometry modeling to minimize numerical errors. Geometry modeling guidelines are provided and then two HF antennas mounted on the Apache Helicopter airframe are modeled. The coupling effects of the two antennas are analyzed in terms of radiation patterns, maximum coupling factors, and input impedance.

9. D.M. Kokotoff, E. El-Sharawy, C.R. Birtcher, "The Radiation Characteristics of a Ferrite-Tuned Cavity-Backed Slot Antenna," **1995 IEEE AP-S Internat. Symp.**, (Newport Beach, CA), June 1995 (to be presented).

   This research focuses on experimentally examining the characteristics of a ferrite-tuned cavity-backed slot (CBS) antenna utilizing magnetostatic wave modes. The cavity is inhomogeneously filled with layers of ferrite and dielectric material. The cavity is fed by a horizontal probe between two layers in the cavity. The gain of the ferrite-loaded CBS antenna has been measured as 2 to 5.6 dBi over a 21% frequency band. Further tuning of the magnetostatic modes was prohibited due to the fixed nature of the applied bias field. No large losses were seen in the ferrite at the resonant frequency corresponding to the applied bias field for the antenna. The operational frequency range strongly depends on the the ferrite material inside the cavity and the position and strength of the applied magnetic bias field. This work demonstrates the practical application of magnetostatic wave modes in the design of CBS antennas.

10. M.C. Medina, C.A. Balanis, "Analysis and Application of the Finite Element Radiation Model Code for Antenna Modeling, **Appl. Comput. Electromag. J.**, accepted.

    The Finite Element Radiation Model (FERM) code is a Moment Method solver implemented for radiation and scattering problems. This code makes use of triangular surface patches to model three-dimensional geometries. This paper addresses the strengths and weaknesses of the FERM code as compared with other national codes. In addition, guidelines are outlined for the various applications of the code.

11. F. Zavosh and J. Aberle, "Analysis of Single and Stacked Circular Microstrip Patch Antennas Backed by a Circular Cavity," **IEEE Trans. Antennas Propagat.**, accepted.

    In this article, a full wave moment method solution for a probe-fed circular microstrip patch antenna backed by a circular cavity both in single and in stacked configurations is presented. For the stacked configuration, the effect of the parasitic patch on antenna bandwidth is considered. In the single patch case, the effect of recessing of the patch into the antenna cavity is studied. In both cases, theoretical results for the scattering and radiation characteristics of the antenna are presented.

12. F. Zavosh and J. Aberle, "Analysis of Post-Tuned Cavity-Backed Circular Microstrip Patch Antennas," **IEE Proc., Microwaves, Antennas, Propagat.**, submitted.

    In this article presents a theoretical investigation of post-loading technique as applied to cavity-backed circular microstrip patch antennas. The effects of the number and location of shorting posts on the polarization and operating frequency of the antenna are analyzed. A number of practical designs using shorting-post loading is also presented.

13. D.M. Kokotoff, F. Zavosh, J.T. Aberle, and E. El-Sharawy. " Hybrid FEM/MoM Analysis of a Cavity Backed Slit Loaded With Anisotropic Material,"**IEE Proc., Microwaves, Antennas, Propagat.**, submitted.

This article presents an analysis of a slit in a dielectric coated ground plane backed by a 2-D cavity. The cavity can be inhomogeneously filled with anisotropic material, and the dielectric coating can contain a perfectly conducting strip. A full-wave frequency domain model is developed wherein the finite element method is coupled with the spectral domain method of moments. The method is validated through comparisons to results generated by other full-wave models. Convergence results for different finite element types are studied. Theoretical results for cavities partially filled with ferrite material are generated. Specifically, the effect of the DC magnetic bias field on ferrite material is studied.

QUARTERLY PROGRESS REPORT

1. Report No. TRC-EM-CAB-9405 entitled "Advanced Electromagnetic Methods for Helicopter Applications," by C. A. Balanis, P. A. Tirkas, *et al.*, Quarterly Progress Report, (January 1, 1995 - March 31, 1995), AHE Program.